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# F-22 Pilot Heart Rate Response to +Gz and Relationship to Pilot Fitness Using U.S. Air Force Fitness Test Scores

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**14. ABSTRACT**

Previous works show heart rate (HR) increases in response to +Gz exposure due to baroreceptor reflex, the physical work of the anti-G straining maneuver, and the physiologic stress of G exposure. Individual fitness predicts resting HR and corresponding increase in HR in response to exercise. The purpose of this study was to look at U.S. Air Force (USAF) F-22 training sortie data to determine whether pilot fitness as characterized by the USAF fitness test components will affect the magnitude of the expected increase in HR over baseline HR in response to +Gz. Fitness parameters from the USAF physical fitness testing program for the pilots flying the sorties during the study timeframe were matched with sortie data and put into a de-identified dataset. These variables were examined using a linear regression model to characterize the relative contribution these variables had on increase in HR over baseline HR obtained at the beginning of the sortie. The dependent variable was Delta HR which is equal to Max Gz HR - Baseline HR. Continuous independent variables were Max Gz, sortie relative time, aero time, pushup count, crunch count, age, and height. Thirty-five percent of variation in Delta HR is explained by model ($R^2 = 0.352642$). The magnitude of +Gz had the greatest impact on HR increase over baseline. Relative time within the sortie of the +Gz exposure also significantly impacted the increase in HR over baseline. Age, height, and pushup count contributed to the increase in HR over baseline. Aerobic time and crunch count were not found to significantly affect HR response. This study provides further insight into the expected HR increase in response to +Gz. It supports the previously known concept that the magnitude of +Gz and pilot height are significant contributors to the increase in HR. Analysis of the USAF physical training program fitness data indicates F-22 pilots as a group are very fit individuals, and we were only able to show that pushup count had a statistically significant effect on HR response to +Gz. The overwhelming effect on HR was due to the magnitude of +Gz.

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# 1.0 SUMMARY

Previous works show heart rate (HR) increases in response to +Gz exposure due to baroreceptor reflex, the physical work of the anti-G straining maneuver, and the physiologic stress of G exposure. Individual fitness predicts resting HR and corresponding increase in HR in response to exercise. The purpose of this study was to look at U.S. Air Force (USAF) F-22 training sortie data to determine whether pilot fitness as characterized by the USAF fitness test components will affect the magnitude of the expected increase in HR over baseline HR in response to +Gz. Continuous physiologic data as well as sortie profile data from USAF F-22 operational training environment were recorded. HR data corresponding to sortie +Gz profile were obtained from sorties over the course of the year beginning November 2012. Fitness parameters from the USAF physical fitness testing program (timed 1.5-mile run, pushups, crunches, height, and age) for the pilots flying the sorties during the study timeframe were matched with sortie data and put into a de-identified dataset. Other potential factors from each sortie were identified, such as +Gz magnitude and elapsed time within a sortie of the +Gz event. These variables were examined using a linear regression model to characterize the relative contribution these variables had on increase in HR over baseline HR obtained at the beginning of the sortie. Dependent variables were Delta HR = Max Gz HR - Baseline HR. Continuous independent variables were Max Gz, sortie relative time, aero time, pushup count, crunch count, age, and height. Thirty-five percent of variation in Delta HR is explained by model ($R^2$ = 0.352642). The magnitude of +Gz had the greatest impact on HR increase over baseline. Relative time within the sortie of the +Gz exposure also significantly impacted the increase in HR over baseline. Age (inverse relationship), height, and pushup count (the only fitness parameter affecting HR) contributed to the increase in HR over baseline. Aerobic time and crunch count were not found to significantly affect HR response. This study provides further insight into the expected HR increase in response to +Gz. It supports the previously known concept that the magnitude of +Gz and pilot height are significant contributors to the increase in HR. Analysis of the USAF physical training program fitness data indicates F-22 pilots as a group are very fit individuals, and we were only able to show that pushup count had a statistically significant effect on HR response to +Gz. The overwhelming effect on HR was due to the magnitude of +Gz.

# 2.0 INTRODUCTION

The F-22 is arguably the world's most advanced fighter operational aircraft; the U.S. Air Force's (USAF) first F-22 came online in April 1997. Starting in 2008, some pilots experienced a constellation of in-flight symptoms that raised operational safety concerns. The F-22 community gained further attention when the fleet was grounded in May 2011 out of an abundance of caution over concerns regarding "hypoxia-like" incidents. As the fleet returned to limited flying operations in September 2011, the USAF led an effort to better understand underlying causes for the observed incidents, which included the collection of in-flight physiologic data from F-22 pilots during training sorties. These data represented a large collection of two physiologic variables (continuous heart rate (HR) and pulse oximetry) obtained in real time over the entire course of F-22 training sorties and were warehoused in the F-22 Library at the USAF School of Aerospace Medicine (USAFSAM). Routinely, aircraft data are collected from the onboard aircraft systems during sorties and are available upon request to the F-22 analysis team at USAFSAM. The USAF also collects fitness parameters for all its



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members in the form of regular physical training (PT) testing, F-22 pilots included. When combined with aircraft data, the opportunity to study influences on physiologic response, specifically HR, to a variety of stimuli is rich with possibilities. In particular, the HR response to G forces in an operational setting could provide more meaningful information than a centrifuge environment might offer.

Heart rate is recognized as an important measure of physiologic response to stimulus, via the sympathetic and parasympathetic systems. Throughout medicine, HR is used to signal changes in physiological states that have bearing on individual health. For instance, obstetric fetal HR monitoring is used to look for signs of fetal distress (decelerations). Resting HR is widely accepted as a function of individual aerobic fitness; the more fit an individual is, the lower the resting HR.

In terms of physiologic response to G forces, forces in the +Gz direction affect primarily the cardiovascular system due to the exaggerated hydrostatic pressure gradient produced by +Gz [1]. The baroreceptor reflex is the parasympathetic feedback mechanism implicated in maintaining cardiac output (CO). As a pilot experiences +Gz, the hydrostatic pressure in the carotid bodies decreases due to pooling of the blood in the dependent portions of the body. Heart rate increases as stroke volume (SV) decreases in response to +Gz to maintain CO in accordance with the equation CO = SV x HR [2]. The physical work of the anti-G straining maneuver (AGSM) and the physiologic stress of G exposure also affect the magnitude of the increase in HR through sympathetic pathways. Conveniently, a non-invasive parameter can be measured in response to +Gz, namely HR response.

The purpose of this study was to look at USAF F-22 operational training sortie data and explore the relative contribution of pilot fitness (using the USAF fitness test as a proxy for fitness) to the expected increase in HR when experiencing +Gz. More specifically, how might pilot fitness as characterized by the USAF fitness test components affect the magnitude of the expected increase in HR over baseline HR in response to +Gz?

## 3.0 METHODS

This study is an analysis of data already collected and therefore used no new equipment or testing facilities. No subjects were recruited specifically for this study. Three primary sources of data were collated into a large dataset for the purposes of this study: 1) physiologic data from F-22 pilots known as the F-22 Library residing at USAFSAM, 2) profile sortie data from F-22 aircraft residing with the aircraft manufacturer, and 3) USAF PT data for the F-22 pilots in this study from the Air Force Fitness Management System (AFFMS).

Subject physiologic data collected for the F-22 Library contain information that was de-identified using a pilot identification (ID) unique to the 711th Human Performance Wing F-22 Analysis Team. All analysts were blinded to subject identities. Pilot pulse oximetry, HR, and date and time for F-22 sorties were initially collected using finger-mounted units that produced a significant amount of artifact. The collection method matured to a helmet-mounted pulse oximeter (HMPO) unit (manufactured by Nonin) that produced more reliable data in November 2012. Flight test evaluation of the HMPO units was conducted and it was concluded the units were safe and reliable for use in the flight environment.[1]

[1] Tripp LD, Brown RW, Sedillo MR, Goodyear C, Pack JS. Helmet-mounted pulse oximetry (HMPO): flight test results and recommendations for operational flight [Unpublished report]. Wright-Patterson AFB (OH): 711th Human Performance Wing; 2012.



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Helmet-mounted pulse oximeter data exist for 5847 sorties. Each sortie contains multiple +Gz exposures and each +Gz exposure is of variable duration. Using only the physiologic data from the sorties with helmet-mounted collection devices, we identified sorties having reliable HR data.

Aircraft sortie profile data (known as integrity data) are routinely collected and available to the 711th Human Performance Wing F-22 Analysis Team. These data are separate from the physiologic pilot data in the F-22 Library and typically reside with the aircraft manufacturer. Parameters include pilot ID, date, time, G vector, and magnitude. Using the Pilot ID and the sortie date and time to match sorties in the F-22 Library, the following aircraft sortie profile data were extracted: Gz magnitude, time elapsed within sortie for Gz exposure (seconds), and Gz duration (seconds). Only Gz exposures greater than 5 g for at least 5 seconds were included. Any exposure that went beyond 10 seconds was excluded.

Fitness data are collected on all USAF members as part of the requirement to maintain physical fitness. Air Force members are required to test at least every 6 months, and those scoring 90 or higher are only required to test annually [3]. The USAF PT test consists of a timed 1.5-mile run (aerobic component), 1 minute of abdominal crunches (reported as a count), 1 minute of military pushups (reported as a count), an abdominal circumference measurement (reported in inches), height (inches), and weight (pounds). The aerobic component, crunch component, pushup component, and abdominal circumference are scored based on age (10-year increments) and gender, then tallied on a scale of 1 to 100 to become the composite score. To pass the PT test, an Airman must reach a minimum threshold for each scored component as well as an overall minimum threshold on the composite score. Exemption for an individual component is possible and granted for medical conditions that might prevent testing in that component, i.e., knee injury generates an exemption from running (may perform a walk test or be exempt from aerobic component) or shoulder pain generates an exemption from pushups.

Using the pilot IDs and sortie dates, the following fitness data were extracted from the AFFMS: test date, age, abdominal circumference (inches), aero time (seconds), pushup count, crunch count, composite score (percent - overall PT score), height, and weight. Body mass index (BMI) was calculated using the height and weight obtained at PT testing time using $(\text{weight}/\text{height}^2)*703$. Physical training test results for an individual pilot closest to the sortie date were selected and appended to the resulting dataset; when the exact same time elapsed between two tests from the sortie date, the more recent test data were used.

Due to the inherent misalignment between data in the HMPO and Integrity Data, the max heart rate reported was from a 2-minute window given Gz exposure boundaries (i.e., 60 seconds up- and downstream). Since a 2-minute window for finding HR was used, any Gz exposures that shared a 2-minute window were excluded. One sortie may generate > 1 Gz exposure.

The resulting HMPO-Integrity-Fitness dataset contained the following (857 records): Pilot ID, Baseline HR, Max HR During Gz, HR Increase Over Baseline, Max Gz, Gz Duration, Sortie Relative Time, Flight Time (seconds), Fitness Test Date, Age, Abdominal Circumference, Aero Time, Pushup Count, Crunch Count, Composite Score, Height, Weight, and BMI. Note the resulting HMPO-Integrity-Fitness dataset contained potentially more than one record per Pilot ID and sortie as more than one Gz exposure in a given sortie might meet suitability criteria. Each record contains only one Gz event, but more than one Gz event may exist for that pilot ID/sortie combination.



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Analysis was conducted using the statistical software SAS, version 9.3 (SAS Institute, Inc., Cary, NC). A linear regression model (PROC GLM) was applied to the HMPO-Integrity-Fitness dataset using Max Gz, Sortie Relative Time, Aero Time, Pushup Count, Crunch Count, Age, and Height.

## 4.0 RESULTS

All subjects in this study were male F-22 pilots who, as a group, were very fit individuals. On average F-22 pilots scored > 90 points (composite score), putting them in the excellent category. Overall aero time showed an average of 661 seconds to run 1.5 miles (7 minutes 21 seconds per mile pace). Pilot mean age was 33.79 years, abdominal circumference was 33.03 inches, pushup count was 55, crunch count was 56, composite score was 94.10, height was 71.22 inches, weight was 186.6 pounds, and BMI was 25.83.

Pilots in the study were grouped by 10-year increments to match the PT test groups (Table 1). Freq shows the number of pilots who fell into the age categories. Each of the subsequent columns is the average for that group. Aero Time represents the number of seconds an individual took to run 1.5 miles. Pushup Count is the number of military-style pushups recorded in 1 minute. Crunch Count is the number of USAF sit-ups recorded in 1 minute. Age was the pilot's age at the time of the PT test. Score is the overall test score achieved on a scale of 1-100. BMI was calculated using the recorded height and weight at the time of the PT test.

**Table 1. Pilot Fitness Averages by Age Group**

| Age (yr) | Freq | Abdominal Circumference (in) | Aero Time (s) | Pushup Count | Crunch Count | Composite Score | Height (in) | Weight (lb) | BMI |
|---|---|---|---|---|---|---|---|---|---|
| 20-29 | 31 | 32.00 | 647.19 | 63 | 58.23 | 94.84 | 70.43 | 177.4 | 24.99 |
| 30-39 | 121 | 33.25 | 663.81 | 60 | 54.73 | 93.48 | 71.33 | 189.5 | 26.15 |
| 40-49 | 26 | 33.00 | 650.69 | 50 | 51.69 | 96.38 | 71.60 | 181.8 | 24.93 |
| 50-59 | 2 | 36.25 | 799.50 | 46 | 48.00 | 90.35 | 70.25 | 209.5 | 29.94 |

Ten fitness records showed an exemption from at least one component of the PT test and were not considered in the analysis; only fitness records where the abdominal circumference, 1.5-mile run, pushups, and crunches were completed were used in the analysis.

Table 2 provides descriptive statistics for the sorties represented in this study. It provides the average and range for each column for all the pilots in the study. Baseline HR was the heart rate at start of sortie. Max HR was the peak heart rate for a given Gz event. Delta HR was calculated using the formula Max HR - Baseline HR. Max Gz was the magnitude of +Gz event. Gz Dur was the duration of +Gz event in seconds. Rel Time was the time of +Gz event within sortie. Flt Time was the total flight time in seconds.



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**Table 2. Sortie Descriptive Statistics**

| Statistic | Baseline HR | Max HR | Delta HR | Max Gz | Gz Dur (s) | Rel Time | Flt Time (s) |
|---|---|---|---|---|---|---|---|
| **Avg** | 75 | 128 | 53 | 7.58 | 16.71 | 0.43 | 6089 |
| **Min** | 42 | 69 | 11 | 5.18 | 5 | 0.021 | 1961 |
| **Max** | 120 | 208 | 116 | 9 | 10 | 0.91 | 17607 |

Multiple linear regression using SAS was carried out. The dependent variable Delta HR was calculated using the formula Max Gz HR - Baseline HR. The continuous independent variables were Max Gz, sortie relative time, aero time, pushup count, crunch count, age, and height (Table 3).

**Table 3. Statistical Model Results**

| Parameter | DF | Mean Square | F Value | Pr > F |
|---|---|---|---|---|
| **Max Gz** | **1** | **65168.12** | **264.72** | **<.0001** |
| **Sortie Relative Time** | **1** | **4566.06** | **18.55** | **<.0001** |
| **Age** | **1** | **2938.66** | **11.94** | **0.0006** |
| **Height** | **1** | **1372.75** | **5.58** | **0.0184** |
| **Pushup Count** | **1** | **1159.68** | **4.71** | **0.0303** |
| Crunch Count | 1 | 369.35 | 1.50 | 0.2210 |
| Aero Time | 1 | 205.52 | 0.83 | 0.3611 |

Thirty-five percent of variation in Delta HR was explained by model ($R^2 = 0.352642$, root mean square error = 15.69011, F value = 65.99, Pr > F is < 0.0001). Note that all parameters had a proportional relationship to Delta HR with the exception of age; age had an inversely proportional relationship. Aero time and crunch count were not found to significantly affect HR response.

## 5.0 DISCUSSION

Because the intent of data collection was to capture data in the event of a "hypoxia-like" event, no pre-sortie protocol standardization for pilots was undertaken. The biggest detractor is that baseline HR is not equivalent to resting HR (lower resting HR is typically thought of as a result of training). A cursory analysis of baseline HR when the same pilot ID had more than one sortie in the dataset revealed ranges for baseline HR could exceed 15 bpm.

Personal factors such as respiratory rate and tidal volume are known to affect HR but such data were not available or controlled for. Other personal factors such as body posture, mood, hormonal status, drugs, and eating habits also affect HR response. Maximal vs. submaximal muscular contraction of the AGSM also might affect HR response. AGSM muscle contraction was not assessed. Genetics contribute to cardiac size and predisposition for certain sports or airframes and were not accounted for in this study. There was no information on the training regimen for these pilots. Factors such as cardiovascular training vs. static exercise



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training are thought to have implications for ability to maintain consciousness when pulling Gs – a direct effect of the hydrostatic influence of +Gz on the cerebral blood pressure. This could also affect HR and was not known for this study.

This study used the USAF PT test as a proxy for fitness. Much debate in the military centers on the topic of fitness testing parameters as a valid measure of ability to conduct military operations. Does the Airman flying a desk require the same level of fitness as a fighter pilot flying a high performance aircraft? Does fitness as measured by the USAF PT test predict ability to meet the physical demands of the mission? Regardless, the USAF PT test offers a measure of generic fitness that arguably is not specific to operational requirements. Anyone who has pulled Gs in the centrifuge or flight environment will say it is strenuous and it behooves the pilot to be in top physical condition.

It is widely thought that muscular fitness over aerobic fitness might benefit the fighter pilot in maintaining consciousness in the aircraft by improving effectiveness of the AGSM. Maintaining consciousness has more to do with oxygen delivery; HR is only one of the mechanisms implicated in the delivery process. It is interesting that pushup count was the only fitness parameter to show a statistically significant contribution to the increase in HR over baseline. While it was not the most significant contributor to Delta HR, it was the fitness parameter that conceivably corresponds to muscular fitness, which is important for the AGSM. It is unclear how muscular fitness might contribute to Delta HR in this study, given the use of the advanced technology anti-G suit in the F-22 and the potentially decreased need to do an AGSM.

## 6.0 CONCLUSION

This study provides further insight into the expected HR increase in response to Gz. It supports the previously known concept that the magnitude of +Gz and pilot height are significant contributors to the increase in HR, which is in keeping with the hydrostatic +Gz effects and the baroreceptor reflex. Analysis of the USAF PT program fitness data indicates F-22 pilots as a group are very fit individuals. Of the fitness parameters, we were only able to show that pushup count had a statistically significant effect on HR response. The lack of a diverse range of fitness levels may have been why other fitness parameters were not found to be significant. In this study, aerobic fitness as measured by the 1.5-mile run had no effect on the increase in HR. The overwhelming effect on HR was due to the magnitude of +Gz.

One aspect this study highlights is that the USAF PT test as a measure of fitness does not necessarily correlate to operational fitness for fighter pilots. The correlation between HR and maintaining consciousness is complex and not easily quantified, making any fitness-based judgments for operational fitness obtuse. The true test for operational fitness is carried out during execution of the mission and not at PT testing time. Yet PT test failures alone can be a cause for dismissal from the military.

This study of operational data lends support to the body of research done using centrifuge subjects to study the physiologic mechanisms under the stresses of pulling Gs. Future studies using centrifuge subjects might consider protocols whose subjects have similar fitness profiles to fighter pilots or might apply study protocols in the operational environment.



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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AFFMS** | Air Force Fitness Management System |
| **AGSM** | anti-G straining maneuver |
| **BMI** | body mass index |
| **CO** | cardiac output |
| **HMPO** | helmet-mounted pulse oximeter |
| **HR** | heart rate |
| **ID** | identification |
| **PT** | physical training |
| **SV** | stroke volume |
| **USAF** | U.S. Air Force |
| **USAFSAM** | U.S. Air Force School of Aerospace Medicine |



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